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APPLICATION FOR U.S. LETTERS PATENT

Title:

TOROIDAL LOW-PROFILE EXTRUSION COOLING SYSTEM AND METHOD
THEREOF

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TOROIDAL LOW-PROFILE EXTRUSION COOLING SYSTEM AND METHOD THEREOF

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from, and incorporates by reference for any purpose the entire disclosure of, U.S. Provisional Application Serial No. 60/463,961 filed April 18, 2003. This application is a Continuation-in-Part of, and incorporates by reference for any purpose the entire disclosure of, U.S. Patent Application No. 09/328,183 filed June 8, 1999

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] Embodiments of the present invention pertain to a cooling apparatus, and more particularly, but not by way of limitation, to cooling systems incorporating toroidally shaped, low-profile extrusions (LPEs).

History of Related Art

[0003] As is explained in greater detail hereinbelow, LPE cooling devices are extremely useful in printed circuit board (PCB) level cooling of electronic components, and for use as heat exchangers in applications where space is limited and/or low weight is critical.

[0004] LPE refers to a heat exchange apparatus including an integral piece of metal having a series of micro extruded hollow tubes formed therein for containing a fluid. LPEs preferably have multi-void extruded tubes (micro-tubes) designed to operate under the pressures and temperatures required by modern environmentally safe refrigeration gases and to resist corrosion. Aspects of the LPE application to the present invention are set forth and shown in co-pending U.S. patent application serial number 09/328,183 (Attorney Docket No. 27889-37) and

10/305,662 (Attorney Docket No. 27889-66) assigned to the assignee of the present invention and incorporated herein by reference.

[0005] LPEs can currently be manufactured with a profile, or height, as low as about 0.05 inches and with tubes of varying inner diameters. Of course, future advances may allow such low-profile extrusions to be manufactured with an even smaller profile. Such low-profile extrusions have been conventionally used in heat exchanger applications in the automotive industry, and are commercially available in strip form (having a generally rectangular geometry) or coil form (a continuous strip coiled for efficient transport).

[0006] An example of a low-profile extrusion is described in a brochure entitled "Thermalex, Inc. -- Setting A Higher Standard in Aluminum Extrusions" (hereinafter the "Thermalex Brochure"). The Thermalex Brochure provides additional detail regarding the Thermalex LPEs and is incorporated herein by reference.

[0007] U.S. Patent No. 5,342,189 to Inamura, et al, which is incorporated herein by reference, provides additional detail regarding an extrusion die for making such LPEs. The extrusion die is used for making multi-cavity flat aluminum tubes, which are used for small heat exchanger components, in automotive air-conditioners, condensers, and radiators. The insert die is composed of a male die section having a protrusion part and a female die section, having a die cavity, and is held detachably in a die holder. The male section is a roughly rectangular plate-shaped component, and has an integrally formed twist prevention region which is inserted into the receiver groove of the female section which is integrally formed on the female section. The protrusion part defines the cavity shape of the multi-cavity flat tube, and the female section has the die cavity of the required cross sectional shape to define the outer shape of the tube.

[0008] U.S. Patent No. 5,353,639 to Brookins, et al, which is incorporated herein by reference, provides additional detail regarding a method and apparatus for sizing a plurality

of micro-extruded tubes used in such LPEs. As described by the Brookins patent, a predetermined number of micro-extruded tubes are stacked on the base fence between the fixed side fence and the clamping fence. The internal webs of the tubes are aligned throughout the stack, perpendicular to the plane of the base fence. The clamping fence is moved toward the stack of tubes to prevent the stack from moving laterally. The die platen is moved toward the stack of tubes and the mating surface of the die platen is in mating engagement with a side surface of the uppermost tube in the stack. A predetermined amount of pressure is applied to the stack of tubes through the die platen. The pressure is applied equally across the entire side surface of the uppermost tube and is transmitted equally through all the tubes of the stack in the sizing die.

[0009] Other developments in cooling apparatus may be seen in U.S. Patent No. 5,285,347 to Fox et al., which describes a hybrid cooling system for electrical components. A hybrid heat sink is specially adapted to transfer heat to two heat transfer fluids. The heat sink is incorporated into a cooling system in which some of the electronic components of an electronic device may be cooled by two heat transfer fluids and some electronic components may be cooled by one heat transfer fluid. The electronic components are mounted on a circuit board. In the Fox reference, one of the heat transfer fluids is air and one is a liquid. The hybrid heat sink is attached to electronic components that cannot be cooled to the normal operating range by the cooling air alone. The cooling air is caused to flow over the surface of the heat sink, removing some of the heat. In addition, the liquid heat transfer fluid is caused to flow through the heat sink, thereby removing additional heat.

[0010] In addition, U.S. Patent No. 5,901,037 to Hamilton, et al. describes a system for closed loop liquid cooling for semiconductor RF amplifier modules. The system includes a combination of a plurality of elongated micro-channels connected between a pair of coolant

manifolds for conducting liquid coolant beneath the transistors to dissipate the heat generated by the transistors. The system also includes a heat exchanger, a miniature circulating pump located on the module, and passive check valves having tapered passages for controlling the flow of coolant in the loop. The valve includes a truncated pyramid-shaped micro-channel valve having no moving parts and is fabricated so as to be a part of either the circulating pump assembly, the coolant manifold, or the micro-channels.

[0011] It has been shown that the use of low-profile heat pipes greatly improves the efficiency of the heat removal process, while making the cooling package lightweight and compact. It is shown in co-pending U.S. Patent Application Nos. 09/328,183 (Attorney Docket No. 27889-37), 10/328,438 (Attorney Docket No. 27889-44), 10/328,537 (Attorney Docket No. 27889-45), 10/335,373 (Attorney Docket No. 27889-68) and 10/345,475 (Attorney Docket No. 27889-69) that heat pipes of the unstacked variety provide superior performance in a low-profile, light weight package.

[0012] Embodiments of the present invention provide a cooling element utilizing a heat pipe with a toroidal shape. The toroidal shape allows the heat pipe to remove heat from a heat generating element while exhibiting a small footprint. The toroidal heat pipe is useful in environments having little space but requiring efficient heat removal.

SUMMARY OF THE INVENTION

[0013] The present invention relates to a heat pipe cooling system and method of manufacture. More particularly, the present invention relates to a cooling system for removal of heat from at least one heat generating component. The system includes a low-profile extrusion having an inner and outer external surface and having a first end and a second end. The low-profile extrusion is curved upon itself such that the second end is disposed generally opposite the first end. The system also includes an interior spaced formed by the inner external surface of the curved low-profile extrusion. The low-profile extrusion has an external surface adapted for thermal connection to the at least one heat generating component. The system also includes a plurality of microtubes formed in the interior of the low-profile extrusion and adapted for containing a heat transfer fluid inside the microtubes, and a fin structure in thermal connection with the exterior surfaces of the extrusion.

[0014] In another aspect, the present invention relates to a method for cooling heat generating elements. The method comprises placing a generally toroidally-shaped heat pipe substantially near at least one of the heat generating elements, and drawing air across the generally toroidally-shaped heat pipe via a fan structure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] A more complete understanding of the method and apparatus of the present invention may be obtained by reference to the following Detailed Description when taken in conjunction with the accompanying Drawings wherein:

[0016] FIG. 1 is a schematic illustration of a low-profile extrusion heat exchange apparatus of an unstacked variety, shown as a circulation cooling apparatus for removal of heat from certain heat generating components;

[0017] FIGs. 2 and 3 are schematic illustrations of another embodiment of the low-profile extrusion heat exchange apparatus of an unstacked variety, shown as the heat pipe type cooling apparatus for removal of heat from certain heat generating components;

[0018] FIG. 4 is a schematic illustration of another embodiment of the low-profile extrusion heat exchange apparatus of an unstacked variety, shown as heat transfer component of a recirculatory system;

[0019] FIG. 5A is a schematic illustration of another embodiment of the low-profile extrusion heat exchange apparatus of an unstacked variety, shown as a liquid to liquid manifold cooling apparatus;

[0020] FIG. 5B is a schematic illustration of another embodiment of the low-profile extrusion heat exchange apparatus of an unstacked variety, shown as a liquid to air manifold cooling apparatus;

[0021] FIG. 5C is a schematic illustration of another embodiment of the low-profile extrusion heat exchange apparatus of an unstacked variety, shown as an air to air manifold cooling apparatus;

[0022] FIG. 6 is a is a schematic illustration of a method and apparatus for manufacturing heat pipes according to an embodiment of the heat exchange apparatus of an unstacked variety;

[0023] FIG. 7 is a schematic illustration of another embodiment of the low-profile extrusion heat exchange apparatus of an unstacked variety, shown as heat pipe base/fin cooling apparatus;

[0024] FIG. 8 is a schematic illustration of another embodiment of the low-profile extrusion heat exchange apparatus of an unstacked variety, shown as a base/heat pipe fin cooling apparatus;

[0025] FIG. 9 is an illustration of one aspect of a stacked array of phase plane heat pipes;

[0026] FIG. 10 is a perspective view of an embodiment of a stacked array of phase plane heat pipes;

[0027] FIG. 11 is a side view of an embodiment of a stacked array of phase plane heat pipes;

[0028] FIG. 12 is an embodiment of a phase plane heat pipe incorporating fins and a fan;

[0029] FIG. 13 is an illustration of a laptop computer including the embodiment of the phase plane heat pipe incorporating fins and a fan as shown in FIG. 12;

[0030] FIG. 14 is an illustration of a laptop computer including another embodiment the phase plane heat pipe incorporating fins and a fan as shown in FIG. 12;

[0031] FIG. 15 is a front perspective view of a toroidally shaped heat pipe according to the principles of the present invention;

[0032] FIG. 16 is a side-elevational view of another embodiment of the toroidally shaped heat pipe of FIG. 15 having a fin structure thermally connected to the top and bottom surfaces of the heat pipe;

[0033] FIGS. 17a - 17e illustrate yet another embodiment of the toroidal heat pipe incorporating a fan and air flow for improved heat removal characteristics;

[0034] FIGS. 18a and 18b illustrate the toroidal heat pipe incorporating a clip for attaching the heat pipe to a heat generating element; and

[0035] FIGS. 19a and 19b illustrate the toroidal heat pipe incorporating springs for attaching said fins to the heat pipe and said heat pipe to a heat generating element.

DETAILED DESCRIPTION OF THE INVENTION

[0036] Various aspects of the present invention are illustrated herein by example in FIGS. 1-19b generally, and more particularly embodiments of the present invention are illustrated by FIGS. 15-19b. Various modifications may be made by a person of ordinary skill in the art. FIGS. 1-14 illustrate utilization of low-profile extrusion apparatus of the unstacked and stacked variety.

[0037] FIG. 1 is a schematic illustration of a cooling apparatus 10 used for removing heat from certain heat generating components 12 mounted on a printed circuit board 14. The printed circuit board 14 may be housed in a host electronic device (not shown) such as computer, a laptop or notebook computer, or other electronic equipment. Due to the ongoing miniaturization of such host electronic devices, the heat generating components 12 are often located in an area of the printed circuit board 14 and of the host electronic device where space is extremely limited, especially in the "z", or height dimension.

[0038] The cooling apparatus 10 generally includes a conventional liquid-to-air heat exchanger 16, an inlet tube 18, a low-profile extrusion 20, an outlet tube 22, a conventional pump 24, and tubing 26. The low-profile extrusion 20 has a plurality of micro-tubes 21, each micro-tube 21 having a micro-tube inlet 21a and a micro-tube outlet 21b.

[0039] Micro-tubes 21 are formed by a plurality of longitudinal members. The longitudinal members may be vertical or may be offset from vertical. A preferred offset from vertical is between about 5° and 60°. More preferably, longitudinal members are offset from vertical by about 30°. Furthermore, longitudinal members may be provided with a capillary groove. The capillary groove may be positioned on an external surface or on the longitudinal members. Further, the capillary grooves may be provided in groups of one, two, three or more.

[0040] Referring again to FIG. 1, the extrusion 20 is preferably formed with a generally flat surface on its underside 20a for contacting heat generating components 12, and may be formed with external fins on its top side 20b to maximize heat transfer, if space allows. It is notable that the micro-tubes 21 formed in the extrusion 20 may be of nearly any geometry and that shapes with flattened heat transfer surfaces are generally preferred, but tubes of any shape could be used with varying degrees of efficiency. As best illustrated in FIGS. 7 and 8, flat extrusions 20 with rectangular micro-tubes 21 are shown. Extrusion 20 is also preferably formed with at least one solid channel (not shown) for mounting to printed circuit board 14. Conventional thermal interface material (not shown) is preferably provided between low-profile extrusion 20 and heat generating components 12.

[0041] The micro-tube inlets 21a of the micro-tubes 21 in the extrusion 20 are interconnected in fluid communication, and to the inlet tube 18, by an inlet endcap 28a. Similarly, the micro-tube outlets 21b of the micro-tubes 21 in the extrusion 20 are interconnected in fluid communication, and to the outlet tube 22, by an outlet endcap 28b. Alternatively, micro-tube outlets 21a and/or 21b may be sealed by crimping the low-profile member 20. Micro-tubes outlets 21a and/or 21b may be individually sealed or connected in fluid communication. The heat exchanger 16 may contain a fluid reservoir (not shown) for housing a heat transfer fluid such as water, glycol, alcohol, or other conventional refrigerants. In addition, a wick, such as a screen may be provided within one or all of micro-tubes 21. The fluid from the heat exchanger 16 is circulated through the inlet tube 18, the low-profile extrusion 20, the outlet tube 22, and the tubing 26 via the pump 24. Alternatively, the entire cooling apparatus 10 may be evacuated and charged with fluid which is then circulated via the pump 24.

[0042] During operation of the host electronic device, heat generated by heat generating components 12 is transferred from heat generating components 12 to an evaporator

section of low-profile extrusion 20, to the fluid circulating within low-profile extrusion 20, and then to heat exchanger 16 from a condenser section of low-profile extrusion 20. Heat exchanger 16 removes the heat from the fluid in a conventional manner. Preferably, an airflow 30 is passed over heat exchanger 16 to aid in such heat removal. Cooling apparatus 10 thus efficiently removes heat from a limited space, low-profile area within the host electronic device (the location of low-profile extrusion 20) to an area where it can be removed at a more convenient location and envelope (the location of heat exchanger 16).

[0043] FIGS. 2 and 3 are schematic illustrations of a cooling apparatus 40 used for removing heat from heat generating components 12 on printed circuit board 14. Referring first to FIG. 2, cooling apparatus 40 generally includes a low-profile extrusion 42 manufactured as a heat pipe capable of phase change heat transfer. A preferred method of making a low-profile heat pipe extrusion 42 is described in greater detail hereinbelow. The low-profile heat pipe extrusion 42 is preferably formed with micro-tubes 41, each micro-tube 41 having a conventional wick structure such as internal fins, grooved inner sidewalls, or metal screens, so as to maximize their heat transfer capability via capillary action.

[0044] To form a heat pipe, the micro-tubes 41 of the low-profile heat pipe extrusion 42 are evacuated and then charged with a fluid such as water, glycol, alcohol, or other conventional refrigerants before sealing the ends 41a and 41b of the micro-tubes 41. The ends may be sealed by crimping. By providing vertically offset longitudinal members, longitudinal members tend to lay over during crimping rather than buckling. Therefore, vertically offset members may be advantageous. As is known in the art, a heat pipe generally has an effective thermal conductivity of several multiples higher than that of a solid rod. Efficiency is increased due to the fact that the phase change heat transfer coefficients are high compared to the thermal conductivity of conventional materials.

[0045] The low-profile heat pipe extrusion 42 is preferably formed into an evaporator section or first portion 44 for contacting heat generating components 12 and a raised or condenser section second portion 46. First portion 44 and second portion 46 are preferably substantially similar in construction to low-profile extrusion 20 of FIG. 1, except endcaps 28 are not required. First portion 44 acts as the evaporator section of the heat pipe, and second portion 46 acts as the condenser section of the heat pipe.

[0046] During operation of the host electronic device, heat generated by heat generating components 12 is transferred from heat generating components 12 to first portion 44. Heat causes the liquid within the micro-tubes 41 in first portion 44 to change to vapor, consuming some of the generated heat. Because the vapor is less dense than the surrounding liquid, the vapor and associated heat rise into the micro-tubes 41 in second portion 46. Of course, heated liquid may also be transferred from first portion 44 to second portion 46 via the capillary action of the wick structures of the micro-tubes. In second portion 46, the vapor condenses into liquid onto the inner side walls of the micro extruded tubes 41. The heat generated by the condensation reaction, as well as any heat transferred via capillary action of the wick structure, is then transferred to air flow 48. Cooling apparatus 40 thus efficiently removes heat from a limited space, low-profile area within the host electronic device (the location of first portion 44) to an area where it can be removed at a more convenient location and envelope (the location of second portion 46). Of course, if low-profile heat pipe extrusion 42 is formed with internal wick structures, it is not necessary that second portion 46 be raised from, or higher than, first portion 44.

[0047] Referring now to FIG. 3, low-profile heat pipe extrusion 42 is shown in operation with a conventional thermoelectric cooler (TEC) 50 in contact with one of the heat generating components 12. A preferred TEC is sold by Marlow Industries, Inc. of Dallas, Texas.

TEC 50 facilitates the heat transfer between the heat generating component 12 and first portion 44 of low-profile heat pipe extrusion 42, and thus is preferred for use with heat generating components 12 that have high power densities.

[0048] FIG. 4 is a schematic illustration of a cooling apparatus 60 used for removing heat from a fluid 62, such as water, glycol, alcohol, or other conventional refrigerants. Fluid 62 is then used to cool conventional heat generating components, such as heat generating components 12 of printed circuit board 14. By way of example, cooling apparatus 60 may be used in place of conventional heat exchanger 16 in FIG. 1.

[0049] Cooling apparatus 60 generally includes a low-profile extrusion 64, an inlet endcap 63a, an inlet tube 66, an outlet endcap (not shown), an outlet tube (not shown), thermoelectric coolers 52, and conventional bonded fin heat sinks 68 and 70. The low-profile extrusion 64 is preferably substantially similar in construction to low-profile extrusion 20 of FIG. 1, with a plurality of micro-tubes (not shown) having a micro-tube inlet and a micro-tube outlet (not shown). The micro-tube inlets of the micro-tubes in the extrusion 64 are interconnected in fluid communication, and to the inlet tube 66, by the inlet endcap 63a. Similarly, the micro-tube outlets of the micro-tubes in the extrusion 64 are interconnected in fluid communication, and to the outlet tube, by an outlet endcap.

[0050] The low-profile extrusion 64 preferably has generally flat bottom and top surfaces for contact with TECs 52. The conventional bonded fin heat sink 68 is coupled to TECs 52 on the top surface of low-profile extrusion 64, and the conventional bonded fin heat sink 70 is coupled to TECs 52 on the bottom surface of low-profile extrusion 64.

[0051] In operation, the low-profile extrusion 64 serves as a manifold, and the TECs 52 remove heat from fluid 62 flowing through the micro-tubes of the low-profile extrusion 64. Heat removed is transferred from TECs 52 to bonded fin heat sinks 68 and 70, which

dissipate the heat to atmosphere in a conventional manner. Preferably, airflows 72 and 74 pass over and through heat sinks 68 and 70 to facilitate such heat dissipation.

[0052] Low-profile extrusion 64 has a smaller size and mass than conventional heat exchanger manifolds. For example, a conventional manifold has a minimum profile, or height, in the "z" direction of about 0.75 inches, and low-profile extrusion 64 may have a profile as low as about 0.1 inches. The reduced mass of low-profile extrusion 64 is believed to produce a cooling apparatus 60 with a near zero time constant, increasing startup performance and temperature control. Therefore, cooling apparatus 60 is especially advantageous in applications involving lasers. The wavelength of a laser beam, and thus beam properties, is strongly influenced by temperature, and the tighter temperature control believed to be provided by cooling apparatus 60 is extremely beneficial.

[0053] FIGS. 5A, 5B, and 5C are schematic illustrations of the cooling apparatus referenced in FIGS. 2-4 incorporating a stacked heat pipe/TEC configuration. FIG. 5A shows a cooling apparatus 80 having a plurality of LPEs 64 and TECs 52 arranged in a serial fashion. A TEC 52 is disposed between, and is in contact with, each of the extrusions 64. Only one low-profile extrusion 64 and one TEC 52 is numbered in FIG. 5A for clarity of illustration. Fluid 62 enters each extrusion 64 via inlet 66 and exits each extrusion 64 via an outlet 82. In operation, TECs 52 remove heat from fluid 62 flowing through LPEs 64. The removed heat is transferred to airflow 84 passing over cooling apparatus 80.

[0054] FIG. 5B shows a cooling apparatus 90 having a plurality of LPEs 64, TECs 52, and low-profile heat pipe extrusions 92 arranged in a serial fashion. More specifically, a TEC 52 is disposed between, and is in contact with, each low-profile extrusion 64 and low-profile heat pipe extrusion 92. Only one low-profile extrusion 64, one TEC 52, and one low-profile heat pipe extrusion 92 are numbered in FIG. 5B for clarity of illustration. Each low-

profile heat pipe extrusion 92 is preferably substantially similar in construction to low-profile heat pipe extrusion 42 of FIG. 1, excluding raised portion 46. Fluid 62 enters each extrusion 64 via inlet 66 and exits each extrusion 64 via outlet 82. In operation, each TEC 52 removes heat from fluid 62 flowing through an adjacent low-profile extrusion 64. The removed heat is transferred to the evaporator portion 92a of the adjacent low-profile heat pipe extrusion 92. The heat is then transferred to the condenser portion 92b of the low-profile heat pipe extrusion 92, as is explained hereinabove in connection with low-profile heat pipe extrusion 42 of FIGS. 2 and 3. An airflow 84 passing over cooling apparatus 90 dissipates heat from each condenser portion 92b of each low-profile heat pipe extrusion 92.

[0055] FIG. 5C shows a cooling apparatus 100 having a plurality of TECs 52 and low-profile heat pipe extrusions 92 arranged in a serial fashion. More specifically, a TEC 52 is disposed between, and is in contact with, each low-profile heat pipe extrusion 92, and the "free end" of adjacent low-profile heat pipe extrusions 92 extend in opposite directions. Only one TEC 52 and two low-profile heat pipe extrusions, 92' and 92'', are numbered in FIG. 5C for clarity of illustration. In operation, a hot airflow 102 flows over each evaporator portion 92a of low-profile heat pipe extrusions 92'. The heat is transferred from evaporator portion 92a to condenser portion 92b of extrusion 92'', as is explained hereinabove in connection with low-profile heat pipe extrusion 42 of FIG. 2 and 3. Condenser portion 92b of extrusion 92'' is in contact with TEC 52. The TEC 52 removes heat from condenser portion 92b of extrusion 92'' and transfers it to evaporator portion 92a of low-profile heat pipe extrusion 92'. The heat is then transferred from evaporator portion 92a to condenser portion 92b of extrusion 92''. Cold airflow 104 passing over condenser portions 92b of each extrusion 92'' dissipates heat from cooling apparatus 100.

[0056] Cooling apparatus 80, 90, and 100 have the same applications and advantages of cooling apparatus 60 described hereinabove. As will be appreciated by one skilled in the art, cooling apparatus 60, 80, and 90 may also be operated as heating apparatus by using thermoelectric coolers (TECs) 52 to heat, rather than to cool, a fluid.

[0057] FIG. 6 is a schematic illustration of a method and apparatus for manufacturing LPEs or heat pipes. As noted hereinabove, the preferred apparatus and method may be utilized to make LPEs of FIGS. 1-4, 5A, 5B, and 5C as well as the extrusions of FIGS. 7-16. However, the preferred apparatus and method may also be utilized to make extruded hollow tubes for other heat exchangers and heat pipes.

[0058] Apparatus 110 generally includes an oven 112 having an insulated housing. A vacuum station 114 and a fluid charging station 116 are in fluid communication with oven 112. Alternatively, stations 114 and 116 may be separate from oven 112. A coil 118 is disposed within a portion of oven 112 on a conventional automatic feed system. Coil 118 may be a coil of hollow tubing, a coil of low-profile extrusion, or a coil of other conventional extrusion having a series of extruded hollow tubes. Furthermore, coil 118 includes any material that can be formed and welded with any fluid fill. The material includes, but is not limited to aluminum, stainless steel, carbon steel, copper, and titanium alloys. An ultrasonic welder/sealer is also provided. One model of ultrasonic welder/sealer is the Ultraseal7 series sold by American Technology, Inc. of Shelton, Connecticut. A brochure entitled "Ultraseal7-20 20kHz Portable Ultrasonic Metal Tube Sealer" (hereinafter the "Amtech Brochure") provides additional information regarding the Ultraseal7 series of ultrasonic welder/sealers and is incorporated herein by reference. A preferred ultrasonic welder/sealer is the Stapla Ultrasonic gantry style seam welder.

[0059] In a conventional process, the first step is actually forming and cutting the heat exchanger, heat pipe, or extruded tubes into the desired configuration. Next, the preformed system is evacuated and charged with a fluid such as water, glycol, alcohol, or other conventional refrigerants. The system is then sealed, completing the process. Conventional processes are expensive because they are labor intensive and require long setup times for different configurations of heat exchangers, heat pipes, or extruded tubes.

[0060] However, apparatus 110 may be used to efficiently and economically produce heat exchangers, heat pipes, and extruded tubes, including LPEs, according to the following preferred process. First, coil 118 is placed within a heat producing device such as oven 112 on the automatic feed system. Second, coil 118 is evacuated using vacuum station 114. Preferably, coil 118 is pulled down to a vacuum of about 10^{-7} torr for a period lasting approximately twenty four hours to many weeks depending on performance requirements. Third, coil 118 is charged with a known amount of fluid, such as water, glycol, alcohol, acetone or other refrigerants, using charging station 116. Acetone is the preferred fluid. Alternatively, coil 118 may be evacuated and charged outside oven 112. Fourth, oven 112 heats coil 118 until at least some of the fluid is in the vapor phase, and the vapor fills the interior of coil 118 evenly. Fifth, using the automatic feed system, the heated and charged coil 118 is reeled out.

[0061] Preferably the fluid exits the oven 112 at approximately 40°C to 60°C allowing enough thermal inertia to draw vapor into the extrusion external to the oven. A temperature sender container may be provided to ensure that the fluid exit temperature is maintained at a desired level. The coil is then processed by crimping, sealing, and cutting the coil 118 into desired lengths. The temperature difference between the oven 118 and the ambient air (or air-conditioned air) temperature condenses the charging fluid in each pipe before it is crimped. These temperatures and flows are used to control the individual heat pipe fills via a

weight analysis. A computer and scale monitor the weight of each part and adjust the oven temperatures accordingly.

[0062] Subsequent steps include crimping, sealing, and cutting the coil 118. A hydraulic press, pneumatic or mechanical means may be used for crimping. An ultrasonic welder/sealer, or another standard welding method such as laser electron beam, resistive, TIG, or MIG welding may be used during the sealing stage. Ultrasonic welding is the preferred process.

[0063] A plasma cutter, or other standard welding method mentioned herein may be used in the cutting stage. However, the plasma cutter is the preferred method. Finished product is collected within container 122. Thus, heat exchangers, heat pipes, and extruded tubes, including LPEs, are formed while charged with fluid, significantly reducing the setup time and vacuum expense over conventional processes.

[0064] In addition, by separating the coil side of the process from the crimping, sealing, and welding process steps, the temperatures for the process steps can be adjusted so as to be in the fluid range for the working fluid. Thus, if a cryogenic heat pipe (charging fluid is typically a gas at normal room temperature) is to be manufactured, the temperature of the process steps would be adjusted such that the charging fluid is a liquid. In a similar manner, high temperature heat pipes, where the charging fluid is typically a solid at room temperatures, can be manufactured.

[0065] Referring now to FIG. 7, there is shown an illustration of another embodiment of a low-profile cooling system of an unstacked variety. A cooling apparatus 210 is used for removing heat from heat generating components 12 on a printed circuit board 14. The cooling apparatus 210 includes a low-profile extrusion 220 manufactured as a heat pipe capable of phase change heat transfer. The low-profile heat pipe extrusion 220 is formed having a plurality of micro-tubes 223, preferably having a conventional wick structure such as internal

fins, grooved inner side walls, or metal screens, so as to maximize the heat transfer capability via capillary action. The micro-tubes 223 of the low-profile heat pipe extrusion 220 are evacuated and then charged with a fluid such as water, glycol, alcohol, or other conventional refrigerants, before the ends of the micro-tubes are sealed.

[0066] Referring still to FIG. 7, the low-profile heat pipe extrusion 220 has a first surface 221 for engaging the heat generating components 12 and receiving heat from the heat generating components 12. On a second surface 222 of the low-profile extrusion 220, a conventional bonded fin heat sink 230 or a plurality of cooling fins are mounted to the low-profile extrusion 220. Preferably, the micro-tubes 223 are disposed in a direction perpendicular to the fins 230 for transferring heat between each of the individual fins 230. The heat transfer between the individual fins 230 promotes an even distribution of heat across each of the fins 230. However, the micro-tubes 223 can be oriented for the transfer of heat along the length of the fins 230. Additionally, in one embodiment, the micro-tubes 223 of the low-profile extrusion 220 are oriented for disbursing heat from the heat generating components 12 to areas of the low-profile extrusion 220 which are not in contact with the heat generating components 12.

[0067] Still referring to FIG. 7, the use of the low-profile extrusion 220 for transferring heat in the cooling apparatus 210 increases the effective surface area that is transferring heat from the heat generating components to the cooling fins 230. The resulting cooling apparatus is therefore smaller in size and lighter in weight for the same effective cooling attributes. In some embodiments, the low-profile cooling system of an unstacked variety can decrease the weight of an apparatus for cooling a heat generating component by as much as 50% over traditional fins mounted via a metal plate.

[0068] Referring now to FIG. 8, there is shown an illustration of another embodiment of a low-profile cooling system of an unstacked variety, showing a cooling

apparatus 250 used for removing heat from heat generating components 12 on printed circuit board 14. The cooling apparatus generally includes a base 260 and a plurality of low-profile extrusion fins 270. The base 260 has a first side 261 for transferring heat between the cooling apparatus 250 and heat generating components 12. The base 260 also has a second surface 262 for mounting the low-profile extrusion fins 270.

[0069] Referring still to FIG. 8, the low-profile extrusion fins 270 are LPEs manufactured as a heat pipe capable of phase change heat transfer. The low-profile extrusion fins 270 are preferably formed with a plurality of micro-tubes 273, each internally having a wick structure such as fins, grooved side walls, or metal screens, so as to maximize the heat transfer capability via capillary action. The micro-tubes 273 of the low-profile extrusion heat piping 270 are evacuated and then charged with a fluid such as water, glycol, alcohol, or other refrigerants, before the micro-tubes 273 are sealed.

[0070] Still referring to FIG. 8, a first end 271 of the low-profile extrusion fins 270 is mounted to the second surface 262 of the base 260 with a second end 272 extending outwardly from the base 260. The plurality of low-profile extrusion fins 270 are preferably mounted in rows for convection heat transfer to the surrounding environment. In one embodiment, the base 260 can also be formed from a low-profile extrusion similar to the low-profile extrusion 220 in FIG. 7.

[0071] Referring still to FIG. 8, the use of the heat pipe type low-profile extrusion fins 270 in the cooling apparatus 250 increases the effective surface area in which heat is transferred from the heat generating components to the surrounding environment via the base 260. The resulting cooling apparatus is therefore smaller in size and lighter in weight for the same effective cooling attributes.

[0072] Referring now to FIG. 9, there is shown an illustration of a stacked, low-profile cooling system 400 with an array of cooling fins secured to an assembly of the low-profile extrusion heat pipes described above. More specifically, the stacked, low-profile cooling system 400 includes a first phase plane heat pipe 401 with fins 403 secured to an undersurface of the heat pipe 401, and fins 405 secured to a top surface of the heat pipe 401. Stacked on top of the phase plane heat pipe 401 is a second phase plane heat pipe 410, also in thermal contact with the cooling fins 405 disposed on the underside of heat pipe 401, and further having a set of cooling fins 412 disposed on a top surface of heat pipe 401. A first thermally conductive spacer block 422 is disposed between the first phase plane heat pipe 401 and the second phase plane heat pipe 410. A third phase plane heat pipe 415 is stacked on top of the first and second phase plane heat pipes 401 and 410 also in thermal contact with the cooling fins 412 and further being assembled with cooling fins 417 stacked on a top surface of heat pipe 401. Similarly, a second thermally conductive spacer block 424 is disposed between the second phase plane heat pipe 410 and the third phase plane heat pipe 415. It may be seen that the cooling fins 403, 405, 412, and 417 include elongated arrays in thermal contact with said phase plane heat pipes.

[0073] As shown herein, an angle between 0 and 90 degrees is suggested relative to the angulated portion of the phase plane heat pipe extending laterally outwardly from element 426, which may be a heat source or a third thermally conductive spacer block disposed beneath the first phase plane heat pipe 401 with a heat generating component 420 disposed underneath (as shown in FIG. 9). The heat source 420 may be any of a plurality of heat generating components, such as computer chips and/or elements within an electrical circuit. As also referenced in FIG. 9, the type of material, either copper or aluminum, has been specified on the thermally conductive spacer blocks 422, 424, and 426. The thermally conductive spacer blocks

422, 424, and 426 provide a conduit for heat transfer from the heat generating component 420 up to and through the stacked, low-profile cooling system.

[0074] Referring now to FIG. 10, there is shown a perspective view of the stacked, low-profile cooling system 400 of FIG. 9. In the embodiment illustrated in FIG. 10, air flow is in the direction of arrow 430. Air is permitted to flow around and through the fins 417, 412, 405, and 403 to provide the cooling of the surfaces of the phase plane heat pipes 401, 410, and 415. Thus, the stacked, low-profile cooling system 400 provide improved operational efficiencies.

[0075] Referring now to FIG. 11, there is shown a side view of the stacked, low-profile cooling system 400 of FIGS. 9-10. The stacked, low-profile cooling system 400, as described above, includes a condenser section 440 where condensing occurs. Likewise, an evaporator section 444 is illustrated in a generally centrally disposed area of the stacked, low-profile cooling system 400 wherein heat is absorbed from the heat source 420. The transfer of the heat by the stacked, low-profile cooling system 400 causes evaporation and the movement of the fluid within the phase plane heat pipes 401, 410, and 415 through adiabatic sections 446 wherein the fluid is allowed to expand without either loss or gain of heat, as is the technical definition of adiabatic. The angle of 0 to 90 degrees as shown herein further facilitates the movement of the evaporated fluid into the extremities of the heat pipes for the condensation of the heat transfer fluid in the condenser sections 440, and the flow of fluid back through the adiabatic sections 446 and into the evaporator section 444 where additional heat may be absorbed.

[0076] Referring now to FIGS. 9, 10, and 11, the stacked, low-profile cooling system 400 illustrates phase plane heat pipes in an innovative manner providing a low-profile and lightweight cooling alternative to conventional heat sinks. The low-profile and flat phase

plane heat pipes provide an ideal surface to attach to a heat generating component and fins to cool the component. Through the stacking of phase planes, heat removal rates of over 100 watts can be achieved for a standard 31 x 31 mm microprocessor, or keep lower wattage microprocessors at a lower operating temperature.

[0077] Referring still to FIGS. 9, 10 and 11 in combination, there is shown the stacks of the phase plane heat pipes 401, 410, and 415 that provide a low-profile, high watt density heat removal design. The materials of construction preferably include copper, aluminum, or other thermally conductive substances. The thermally conductive spacer blocks 422, 424, and 426 above described and secured to the heat generating component 420 (as shown in FIG. 9) may be formed of the same materials. The attachment process can be done through mechanically compressing the heat generating device to the heat sink with a thermal pad or thermal grease in between. The specific mounting mechanism is not shown herein and can include a variety of methods currently used in the heat sink market place. The base stack that is in contact with the heat generating component may also be the phase plane heat pipe as well. The fins 403, 405, 412, and 417 can be attached on both sides of the phase plane heat pipes 401, 410, and 415 providing surface area for the air/heat exchange to reduce the temperature of the cooling system 400 of FIGS. 9-11, and thus the heat generating component 420. Air is ducted across the cooling fins 403, 405, 412, and 417 and the heat pipes 401, 410, and 415 in the manner shown in FIGS. 9-11.

[0078] Again referring to the operation of the stacked, low-profile cooling system 400, the evaporator section 444 include that region of the phase plane heat pipes where the heat generating component 420 is positioned, as best illustrated in FIG. 11. The condenser sections 440 of the phase plane heat pipes located toward the ends provide for the recirculation of the heat transfer fluid and through the adiabatic sections 446. Significant increases in performance

are provided when gravity aids the operation of the individual phase plane heat pipes. The design can have an angular range from 0 (horizontal) to 90 (vertical), depending on the design parameters required for a particular device. Through the stacking approach and increased effective fin-surface area, the stacked, low-profile cooling system will provide superior performance in a low-profile package.

[0079] Referring now to FIG. 12, there is shown an alternative embodiment of the stacked, low-profile cooling system incorporating a possible design for a laptop computer. A heat generating component 487 is shown in phantom and may include a printed circuit board disposed in a laptop computer. In the embodiment illustrated in FIG. 12, air is sucked into a fan 480 as shown by arrow 486. As shown by arrow 485, air is blown out the sides through fin stock 482 mounted upon at least one phase plane heat pipe 484 of the type set forth and described in FIGS. 9-11. The evaporator section 470 of the phase plane heat pipe 484 is thermally and mechanically affixed to the heat generating component 487. The fins 482 are placed on the condenser section 471 to aid in cooling. A 0 to 90 orientation may be placed on the phase plane 484 between the evaporator section 470 and the condenser section 471. In another embodiment, a stacked array of heat pipes may be utilized in accordance with the stacked, low-profile cooling system, as well as the utilization of a phase plane heat pipe on both sides of the fan 480.

[0080] Referring now to FIG. 13, a laptop computer 500 including an embodiment of the stacked, low-profile cooling system of FIG. 12 is described. The fan 480 is disposed in a corner beneath a keyboard 502 and above a heat source 501 such as a circuit board. Air is drawn in to the fan 480 and dispersed outward through the fin stock 482. Although the fin stock 482 is illustrated as being positioned vertically in the laptop, the fin stock 482 may also be positioned in other orientations, such as horizontally.

[0081] Referring now to FIG. 14, there is shown another embodiment of the stacked, low-profile cooling system of FIG. 12 disposed in a laptop computer 500. In the embodiment illustrated in FIG. 14, a fan 550 is connected with two fin stocks 560 for dispersing heat. The fan 550 may be located anywhere within the laptop 500 and have one or more fin stocks 560 associated with the fan 550. The fin stocks 560 may be located at opposite sides of the fan 550, or form an L-shape. The fan 550 may also have more than two fin stocks 560 associated with the fan.

[0082] Various embodiments of the stacked, low-profile cooling system may also include cross configurations where the phase plane heat pipes extend orthogonally one to the other and/or at angles acute to each other for purposes of positioning around components within an electrical system, such as a computer, and/or to improve air flow and to improve the thermal efficiency of the components of the electrical system.

[0083] Referring now to FIG. 15, there is shown an embodiment of a generally toroidally-shaped heat pipe coil cooling system 600 according to the principles of the present invention. The cooling system 600 removes heat from any heat source through an evaporation and condensation process similar to that described above in relation to FIGS. 2-3 and 9-14. Embodiments of the present invention, as illustrated below may function in any orientation, such as a vertical or a horizontal configuration. The cooling system 600 may include one or more heat pipes 602 with ends 604 and 606. The sealed ends 604, 606 may be tapered or of a consistent width as desired. The heat pipe 602 is curved or bent upon itself (as shown herein) to form a coiled or generally toroidally-shaped heat pipe 602 as shown herein so that the ends 604, 606 may be in close proximity to one another or direct contact with one another. The generally torodial shape of the heat pipe 602 creates a generally central void 608. Further, the heat pipe

602 may include a plurality of micro-tubes (not shown) internally as described above in relation to FIGS. 2-3 and 9-14 or the heat pipe 602 may include a single hollow tube.

[0084] In the embodiment illustrated in FIG. 15, the heat pipe 602 may optionally include a generally planar portion 610 for facilitating the mounting to, and/or coupling with a system including heat generating component 612. The planar portion 610 of the heat pipe 602 creates a large area of surface contact between the heat pipe 602 and the system including heat generating components 612. By increasing the amount of surface area of the heat pipe 602 that is in contact with the system including heat generating components 612, the amount of heat that is absorbed and allowed to dissipate through the heat pipe 602 may be increased. Although shown with a barrier between the heat pipe 602 and the heat generating components 612, the heat pipe 602 may be in direct contact with the heat generating components 612 in accordance with embodiments of the present invention.

[0085] With further reference to FIG. 15, in operation, the heat pipe 602 of cooling system 600 includes a condenser section 614 and an evaporator section 616. The heat pipe 602 is charged with a heat transfer fluid such as, for example, glycol, alcohol, acetone or any other type of heat transfer fluid. Heat generated by the heat generating component 612 is transferred to the evaporator section 616 of the heat pipe 602. The heat transfer fluid in the micro-tubes of the heat pipe 602 changes to vapor as the heat transfer fluid absorbs the heat radiated from the heat generating components 612. The vapor then rises through the heat pipe 602 and collects in the condenser section 614. As the vapor cools in the condenser section 614, heat is transferred to the surrounding environment, thus efficiently removing heat from the heat generating components 612.

[0086] Referring now to FIG. 16, there is illustrated another embodiment of the cooling system of FIG. 15. In FIG. 16, the cooling system 600 includes an inner fin structure

700 in thermal connection with an inner surface 702 of the heat pipe 602 to facilitate heat removal from a heat generating component 703. In addition, an outer fin structure 704 may be in thermal connection with an outer surface 706 of the heat pipe 602 to facilitate heat removal from the heat generating components 612. Although the illustrated embodiment shows an inner fin structure 700 in thermal connection with substantially the entire inner surface 702 of the heat pipe 602, select portions of the heat pipe 602 may be in thermal contact with an inner fin structure 700. For example, the inner fin structure 700 may be oriented at the condenser section 614. Similarly, although the illustrated embodiment shows an outer fin structure 704 in thermal contact with substantially the entire outer surface 706 of the heat pipe 602, excluding the planar portion 610, the outer fin structure 704 may be positioned at select portions of the heat pipe 602, i.e., the condenser section 614. In addition, the inner and/or outer fin structures 700, 704 may terminate at each end 604, 606 or may be continuous across the ends 604, 606.

[0087] Referring now to FIG. 17a, there is shown frontal view of the cooling system 600 incorporating the inner and outer fin structures 700, 704, and also including a fan structure 800. Some portions of the inner fin structure 700 have been eliminated in FIG. 17a for clarity purposes. The fan structure 800 may be any type of fan used in the electronics industry for blowing air in an electronic environment. The inner fin structure 700 may have a height dimension that extends to a portion of the fan structure 800 having little or no air flow, known as the dead spot. When the fan structure 800 is active, air is directed through the inner and/or outer fin structures 700, 704 to increase heat removal. The fan structure 800 may have a diameter that is smaller or larger than the body of the cooling system 600. It may be seen that the generally torodial shape of the heat pipe 602 effectively maximizes the effectiveness of the fan structure 800 so that a generally cylindrical column of air is drawn by the fan structure 800 and the air

flow through the cooling system may therefore be maximized as shown in greater detail in FIGS. 17d and 17e.

[0088] Referring now to FIGS. 17b-c, a side elevational view of the cooling system 600 is shown mounted to the fan structure 800. As shown in FIG. 17b, the cooling system 600 and fan structure 800 may be mounted to a base 802 by screws, adhesives, or other conventional bonding techniques known in the art. As illustrated in FIG. 17C, the fan structure 800 may be mounted directly to the cooling system 600. The fan structure 800 may or may not have the same dimensions as the cooling system 600.

[0089] Referring now to FIGS. 17d-e, a side elevational view of the cooling system 600 and fan structure 800 including a diagrammatic schematic of an associated air column 802 is shown. The air column 802 created by the fan structure 800 is generally cylindrical in shape, matching the general shape of the cooling system 600. Thus, the energy used to create the air flow is efficiently used by maximizing available air flow around and/or through the fin structures 700 and 704 and minimizing air flow outside the cooling system 600 or inside the void 608. Increased efficiency in this aspect of the cooling system 600 maximizes the cooling effectiveness in accordance with principles of the present invention.

[0090] Referring now to FIGS. 18a and 18b in combination, there is shown a cooling system 600 in accordance with principles of the present invention. In the embodiment illustrated in FIGS. 18a and 18b, a base plate 902 sits atop the planar portion 610 of the heat pipe 602. The planar portion 610 of the heat pipe 602 sits atop a heat generating element (not shown). The base plate 902 functions as a clip that causes the planar portion 610 of the heat pipe 602 to maintain contact with the heat generating component. As shown in this embodiment, the inner fin structure 700 above the planar portion 610 has been eliminated to accommodate the base plate 902.

[0091] Referring now to FIGS. 19a and 19b in combination, there is shown another embodiment of the cooling system 600 of the present invention. The cooling system 600 incorporates a set of springs 1001 and 1002. In the embodiment illustrated in FIGS. 19a-19b, the springs 1001 and 1002 attach the cooling system 600 to a heat generating component (not shown). The inner spring 1001 rests in the void 608 created by the toroidal-shaped heat pipe 602. The outer spring 1002 is oriented along an outer surface of the outer fin structure 704. Thus, the heat pipe 602 may be mounted to the heat generating element without the use of thermal epoxies or soldering. The springs 1001 and 1002 exert opposing forces such that the fin structures 700, 704 are in thermal contact with the heat pipe 602. The use of the inner spring 1001 and the outer spring 1002 makes the cooling system 600 wider and allow the inner fin structure 700 to extend throughout the inner surface of the toroidal-shaped heat pipe 602 while allowing the heat pipe 602 to maintain direct contact with the heat generating element (not shown).

[0092] Referring now to FIGS. 15, 16, 17a-c, 18a-b, and 19a-b, in combination, the heat pipe 602 may be a mass produced product that is processed through a tool. A graphite interface material used between the heat pipe 602 and the heat generating component 612 as well as between the fin structures 700, 704 and the inner and outer surfaces of the heat pipe 602. The use of graphite, in essence, increases the thermal efficiency of the cooling system 600.

[0093] It is believed that the operation and construction of the present invention will be apparent from the foregoing description of a preferred embodiment. While the device shown is described as being preferred, it will be obvious to a person of ordinary skill in the art that various changes and modifications may be made to the device without departing from the spirit and scope of the invention as defined in the following claims. Therefore, the spirit and the

scope of the appended claims should not be limited to the description of the preferred embodiments contained herein.